3.1   Virtual Simulation of Vision 21 Energy Plants

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Abstract

The Vision 21 Energy plants will be designed by combining several individual power, chemical, and fuel-conversion technologies. These independently developed technologies or *technology modules* can be interchanged and combined to form the complete Vision 21 plant that achieves the needed level of efficiency and environmental performance at affordable costs. The knowledge about each technology module must be captured in *computer models* so that the models can be linked together to simulate the entire Vision 21 power plant in a *Virtual Simulation* environment. Eventually the Virtual Simulation will find application in conceptual design, final design, plant operation and control, and operator training. In this project we take the first step towards developing such a *Vision 21 Simulator*.

There are two main knowledge domains of a plant – the process domain (what is in the pipes), and the physical domain (the pipes and equipment that make up the plant). Over the past few decades, commercial software tools have been developed for each of these functions. However, there are three main problems that inhibit the design and operation of power plants: 1. Many of these tools, largely developed for chemicals and refining, have not been widely adopted in the power industry. 2. Tools are not integrated across functions. For example, the knowledge represented by computational fluid dynamics (CFD) models of equipment is not used in process-level simulations. 3. No tool exists for readily integrating the design and behavioral knowledge about components. These problems must be overcome to develop the Vision 21 Simulator. In this project our

major objective is to achieve a seamless integration of equipment-level and process-level models and apply the integrated software to power plant simulations. Specifically we are developing user-friendly tools for linking process models (Aspen Plus) with detailed equipment models (FLUENT CFD and other proprietary models). Such integration will ensure that consistent and complete knowledge about the process is used for design and optimization.

The technical objectives of the current project are the following: Develop a software integration tool called the *V21-Controller* to mediate the information exchange between FLUENT, other detailed equipment models, and Aspen Plus. Define and publish software interfaces so that software and equipment vendors may integrate their computer models into the software developed in this project. Demonstrate the application of the integrated software with two power plant simulations, one for a conventional steam plant and another for an advanced power cycle.

The project was started in October 2000. Highlights of the accomplishments during the first year of the project are the following: Formed a multi-disciplinary project team consisting of chemical and mechanical engineers; computer scientists; CFD, process simulation, and plant design software developers; and power plant designers. Developed a prototype of CFD and process model integration: a stirred tank reactor model based on FLUENT was inserted into a flow sheet model based on Aspen Plus. The prototype was used to show the effect of shaft speed (a parameter in the CFD model) on the product yield and purity (results of process simulation). This demonstrated the optimization of an equipment item in the context of the entire plant rather than in isolation. Conducted a user survey and wrote the User Requirements, Software Requirements and Software Design documents for the V21-Controller. Adopted CAPE-OPEN standard interfaces for communications between equipment and process models. Developed a preliminary version of the V21-Controller based on CAPE-OPEN interfaces. Selected one unit of an existing conventional steam plant (Richmond Power & Light) as the first demonstration case and developed an Aspen Plus model of the steam-side of the unit. A model for the gas-side of the unit, based on ALSTOM's proprietary model INDVU, was integrated with the Aspen Plus model. An industrial Advisory Board was formed to guide the software development effort and one Advisory Board meeting was conducted.

Because we are integrating widely used commercial software (Aspen Plus and FLUENT) we expect that the results of the project will find immediate commercial applications at the conclusion of the project.

The future activities planned are the following: Complete and test the V21-Controller and complete the integration between process-level and equipment-level models. Conduct power plant Demonstration Case 1 simulations with the integrated software suite. Select power plant Demonstration Case 2 and conduct simulations. Prepare a mock up of a 3-D plant walk through to assess the integration of process and physical domain software in a future phase of the project.

Virtual Simulation of Vision 21 Energy Plants

Vision 21 Program Review Meeting
November 6-7, 2001

Acknowledgement

vision 21
a concept for tomorrow's
pollution-free energy plant

Vision 21 Program Review
Meeting, Nov. 6-7, 2001

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Acknowledgement

Lewis Collins, Paul E. Felix, Maxwell O. Osawe, Madhava Syamlal
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Aspen Technology, Inc

Frank Joop
Intergraph Corporation

Joseph Cleetus, Igor B. Lapshin
CERC, West Virginia University

Diane Revay Madden
DOE Project Manager
National Energy Technology Lab

and

Members of the Advisory Board

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Virtual Simulation of Vision 21 Plants

- Vision 21 plants will be developed by combining multiple technology modules

- How will the information from modules be used for evaluating Vision 21 concepts?

- Use computer simulation for evaluating V21 plants:

  - Demonstrations are becoming difficult: cost is increasing; R&D dollars are decreasing

  - Simulations are becoming more attractive: cost is decreasing; fidelity is increasing

  - Perform <u>Virtual Simulation</u> by linking computer models that contain information about the modules: Computational Fluid Dynamics (CFD), equipment-level models, process flow sheets, plant layout and 3D visualization

- Need to develop methods for integrating software

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Many Tools are Currently in Usage

- Process domain (what is in the pipes)
  - Proprietary equipment models – INDVU
  - CFD – Fluent
  - Process modeling – Aspen Plus
- Information Management
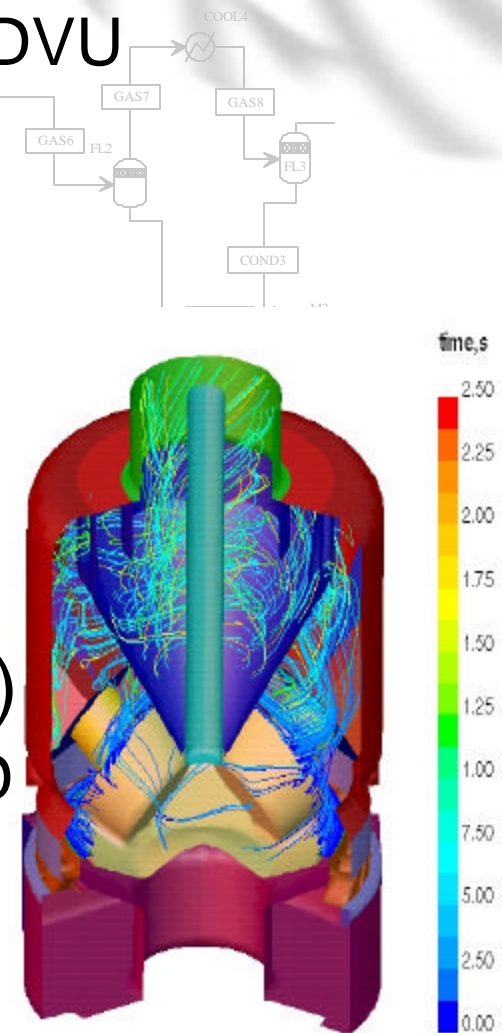 - Front-end design – Aspen Zyqad
  - Data Warehouse – Notia
- Physical domain (the pipes and equipment that make up the plant)
  - Plant Design – SmartPlant P&ID/3D
 - Stress analysis – Ansys/Structural
  - Visualization – SmartPlant Review

Pathlines in mill simulation.

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Barriers to Virtual Simulation

- Many of these tools, largely developed for chemicals and refining, have not been adopted by the power industry

- Tools are not integrated across functions – e.g., knowledge represented by CFD is not used in process simulation

- Knowledge not captured in a component-oriented manner to readily create new power plant designs
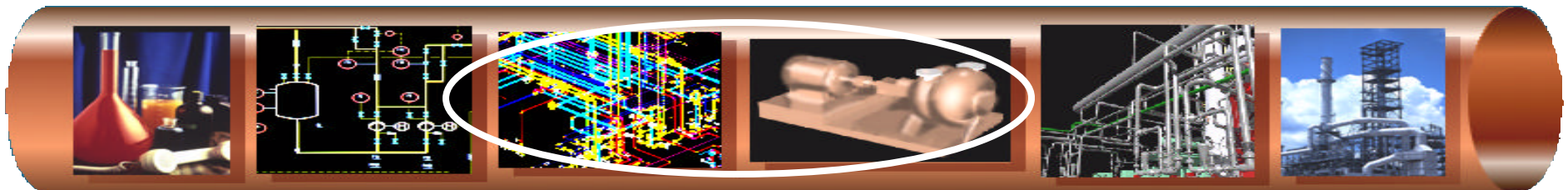
| **Finance/ Planning/R&D** | **Conceptual Design** | **Process Engineering** | **Detailed Engineering** | **Construction/ Start-up** | **Operations/ Asset Mgt** |

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Project Vision

- Integration of process data and models from equipment-level to plant-level to ensure that design is based on consistent and complete process knowledge

  - Same physical properties used in equipment and process models

  - Detailed information about critical equipment, (e.g. CFD model) is easily propagated to process models

- Use of open industry-standard interfaces for software integration

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Project Technical Objectives

- Integrate plant simulation software:
  - plant-level, process flowsheet model (Aspen Plus)
  - equipment-level models based on CFD (FLUENT)
  - proprietary equipment-level models (Alstom Power)
  - equipment-performance visualization tools
- Develop *V21 Controller* software to make the integration user friendly
- Demonstrate capabilities on realistic power plant designs
- Organize Industry Advisory Board to guide work and ensure that the results are put into practice

Project Team
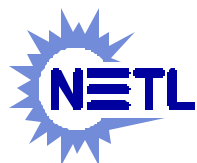
FLUENT

**Cooperative Agreement
National Energy Technology Lab**

NETL

FLUENT INCORPORATED

Fluent, Inc.
Project management
Software development

aspentech
process. to the power of e.

Aspen Technology, Inc.
Prototype development
Aspen Plus consultation

West Virginia University
(CERC)
Software development

CERC
West Virginia University

ALSTOM

Alstom Power, Inc.
Demonstration cases
Proprietary code interfaces

Intergraph Corporation
Plant design software
consultation

INTERGRAPH

Industry Advisory Board

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Accomplishments and Next Steps

- **Software Integration (Task 2.0)**
  - [Developed a Prototype](#)
  - Completed top-level design of *V21-Controller*
  - Implemented CAPE-OPEN interfaces in Fluent
  - Developed COM-CORBA bridge
  - [Status/Next Steps](#)

- **Software Demonstration (Tasks 3.0 & 4.0)**
  - Selected a conventional steam plant (RP&L) for Demo Case 1
  - Created a process model of RP&L plant using Aspen Plus
  - Integrated INDVU code with RP&L process model
  - [Status/Next Steps](#)

- [**Industrial Advisory Board**](#) (Task 5.0)

Fluent-Aspen Plus Prototype

Integrated Aspen Plus / Fluent Demonstration
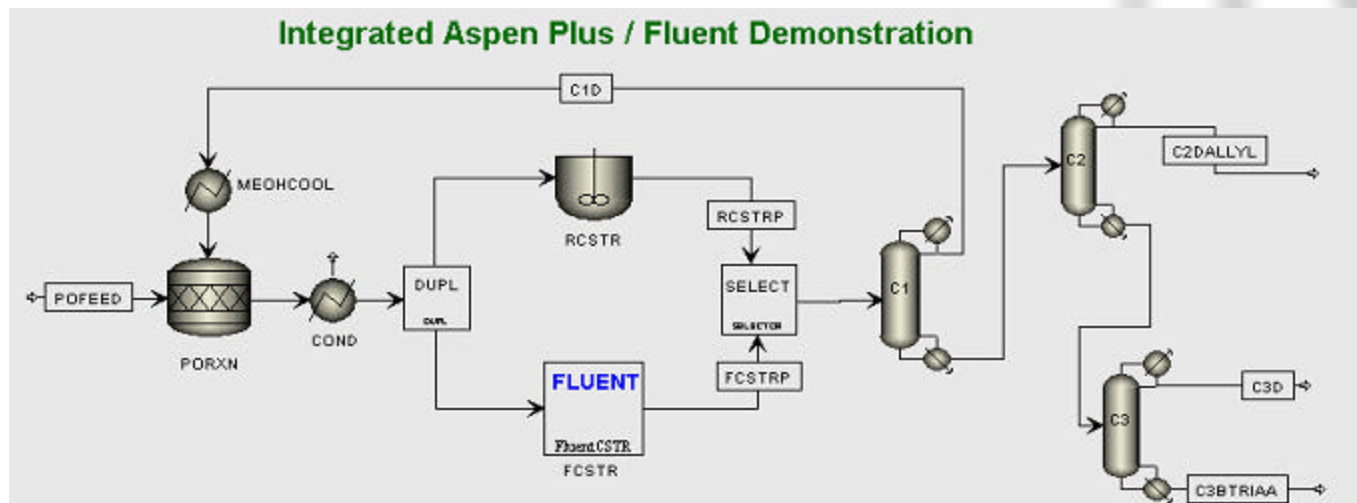
- Aspen Plus steady-state simulation of allyl and tri-acetone alcohol production
- Distillation columns for product and solvent separations

- CFD Model accounts for the effect of fluid mixing on chemical reactions
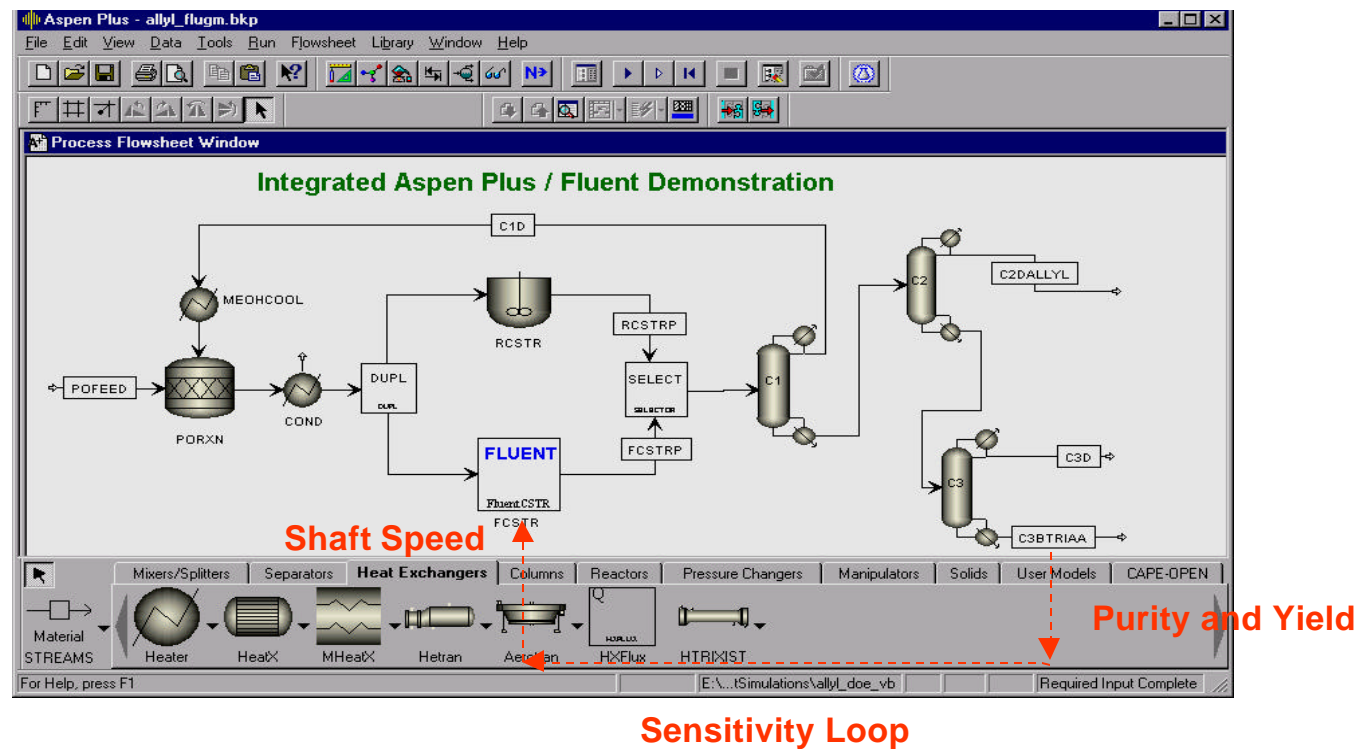- Fluent CSTR model is embedded in a recycle loop

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Fluent Integrated with Aspen Plus Using CO Interfaces
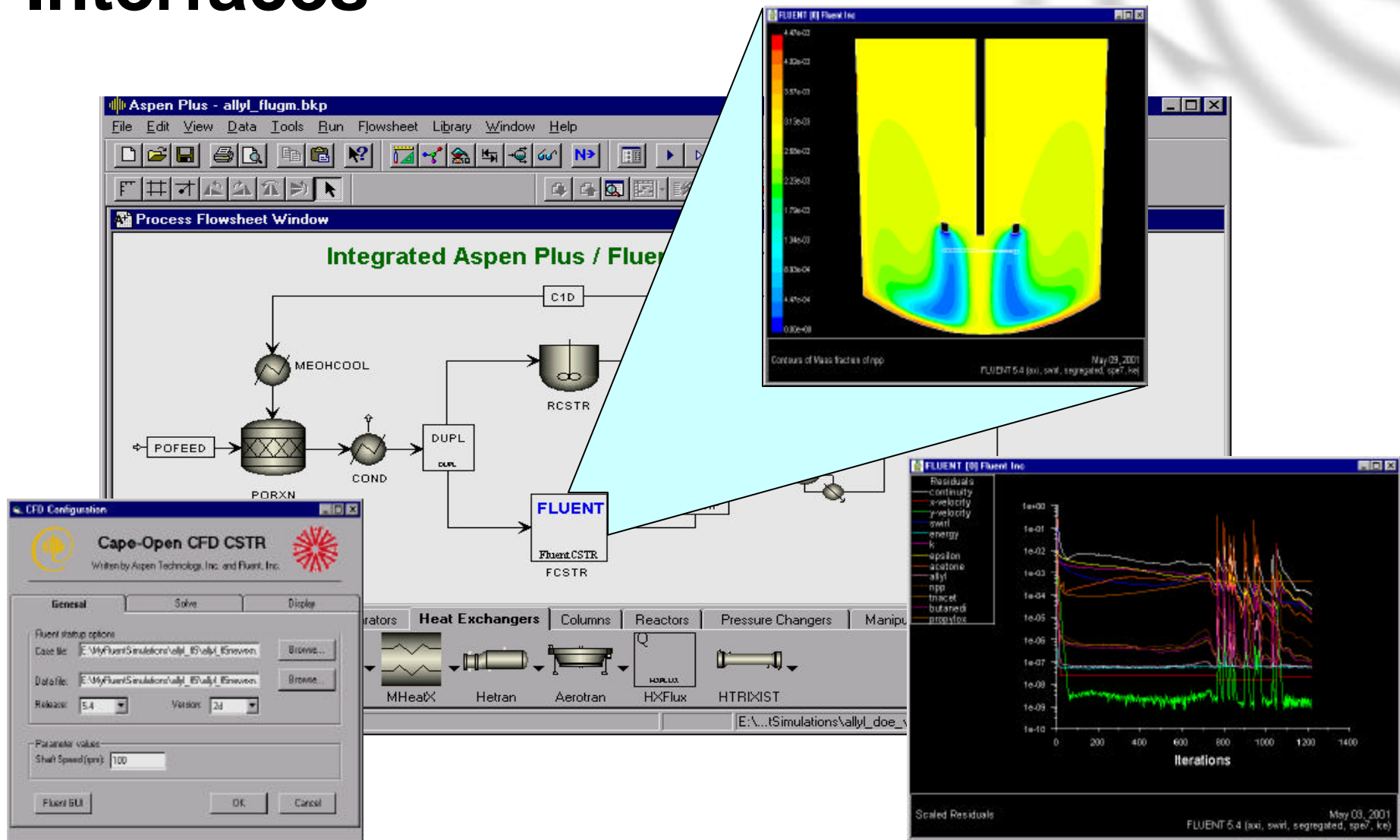
Fluent-Aspen Plus Sensitivity Analysis

- How do product purity and yield react to varying Fluent CSTR shaft speed (mixing)?

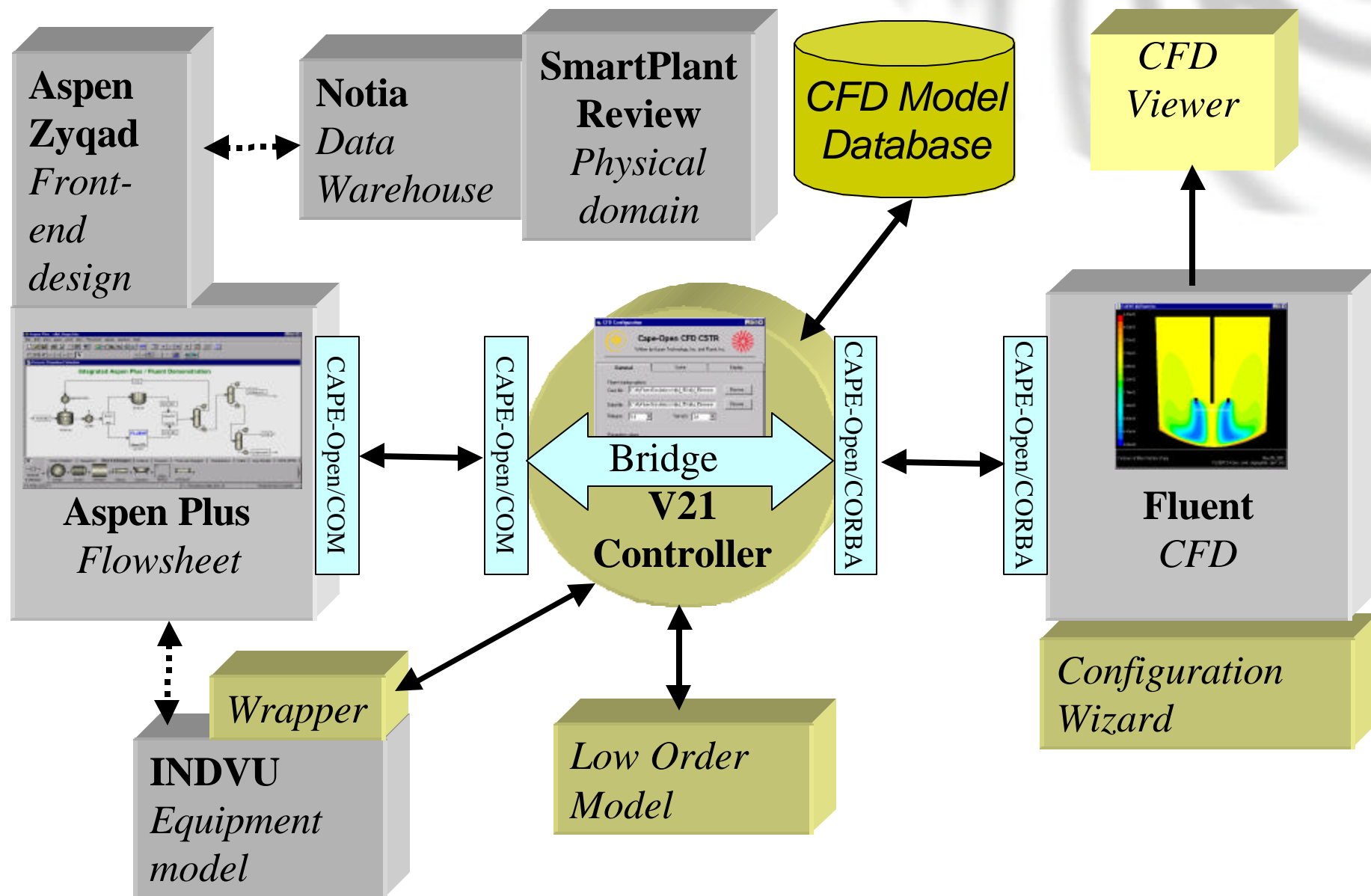Vision 21 Program Review
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Equipment Optimization in the Context of the Entire Plant

- Effect of fluid dynamics (degree of mixing) is accounted for in process simulation

- Integration allows user to optimize shaft speed (CFD variable) with respect to product purity and yield (process variable)

Software Architecture

FLUENT

Aspen Zyqad *Front-end design*

Notia *Data Warehouse*

SmartPlant Review *Physical domain*

CFD Model Database

CFD Viewer

Aspen Plus *Flowsheet*

CAPE-Open/COM

CAPE-Open/COM

Bridge V21 Controller

CAPE-Open/CORBA

CAPE-Open/CORBA

Fluent *CFD*

Configuration Wizard

Wrapper

INDVU *Equipment model*

Low Order Model

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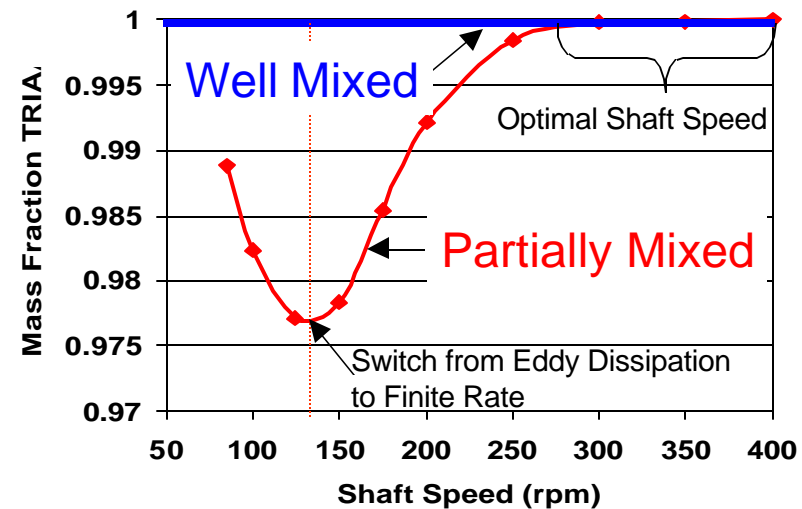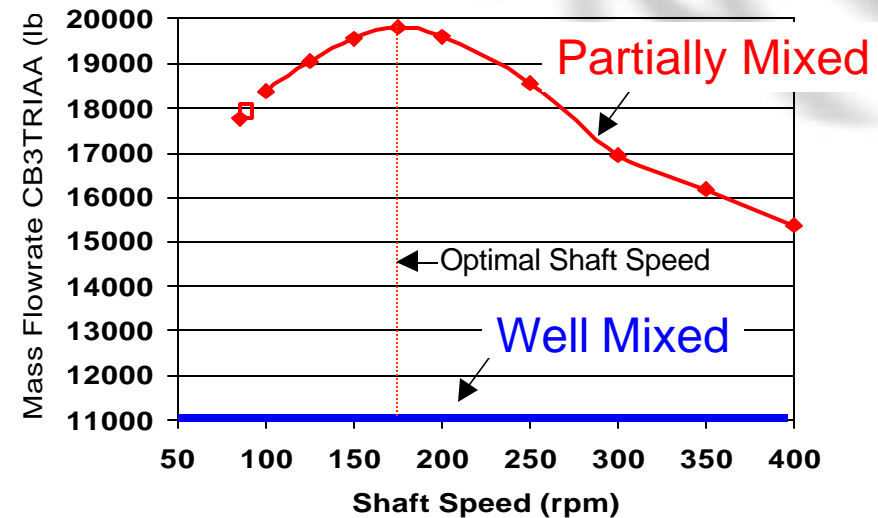
CAPE-OPEN

- Open standard interfaces defined by the "Computer-Aided Process Engineering - OPEN simulation environment" project
  - Unit Operations
  - Physical Properties
  - Numerical Solvers
  - Reaction Kinetics
- European CAPE-OPEN Project (1997-99)
  - 15 partners, including AspenTech
- Global CAPE-OPEN (1999-2001)
  - 30 partners in Europe, USA, Canada, Japan
- Project collaborates with GCO through Norsk Hydro
- Early usage of CO interfaces for CFD
- Identified areas for improvements
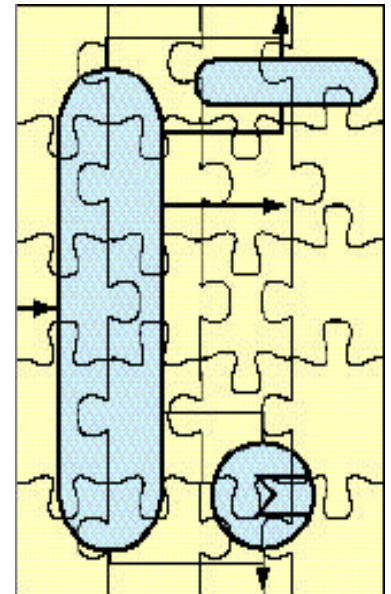
Demo Case 1: RP&L Conventional Steam Plant

- Lead by ALSTOM Power
- Create model of the 33 MWe Richmond Power & Light power plant
- Conduct three runs of increasing complexity, using:
  - Aspen Plus library components
  - ALSTOM Design code
  - FLUENT™ CFD
- Perform calculations as a function of generator output (or load)
- Assess simulation efficiency and provide feedback to software designers

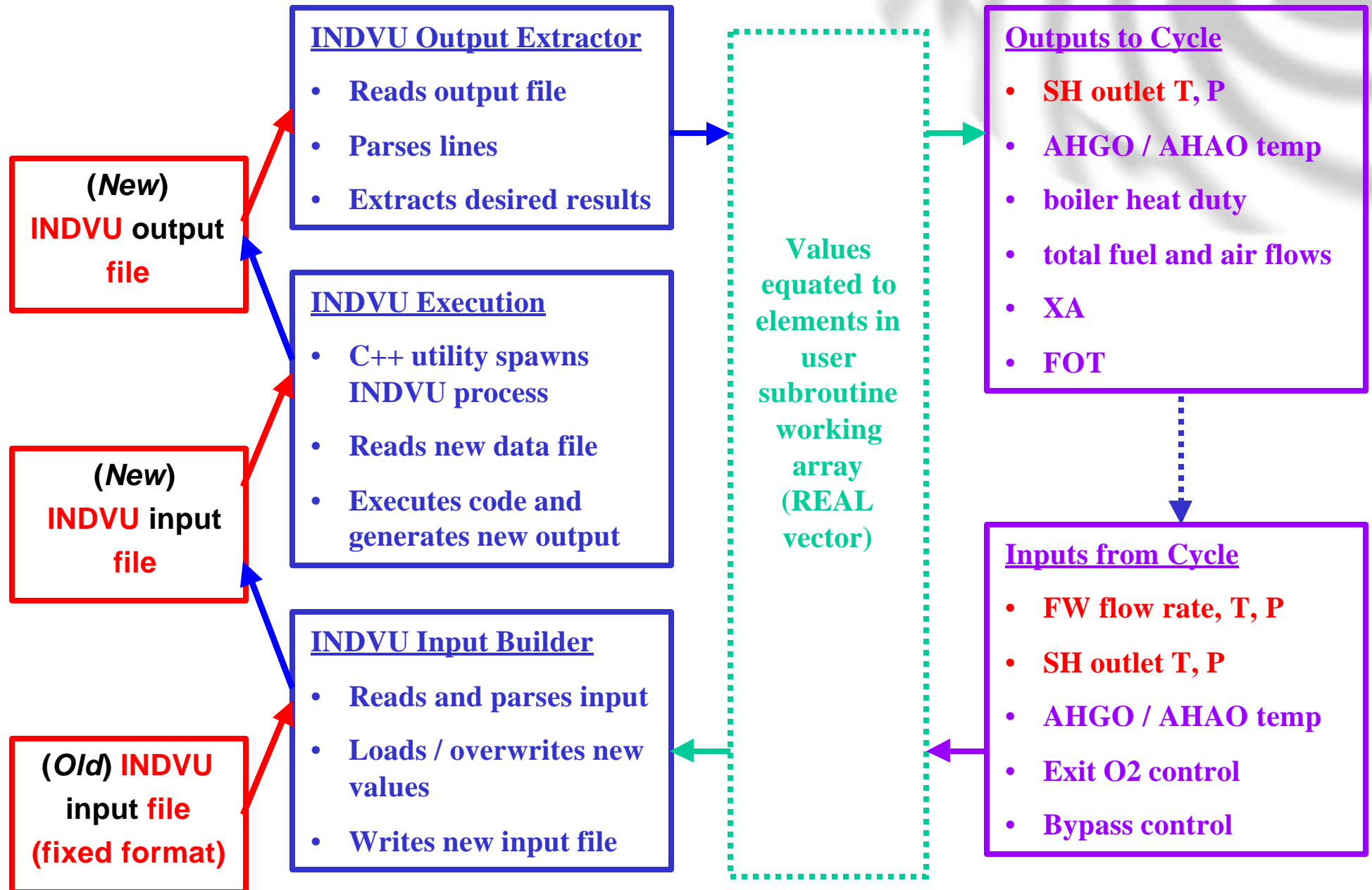Vision 21 Program Review
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RP&L Process Model
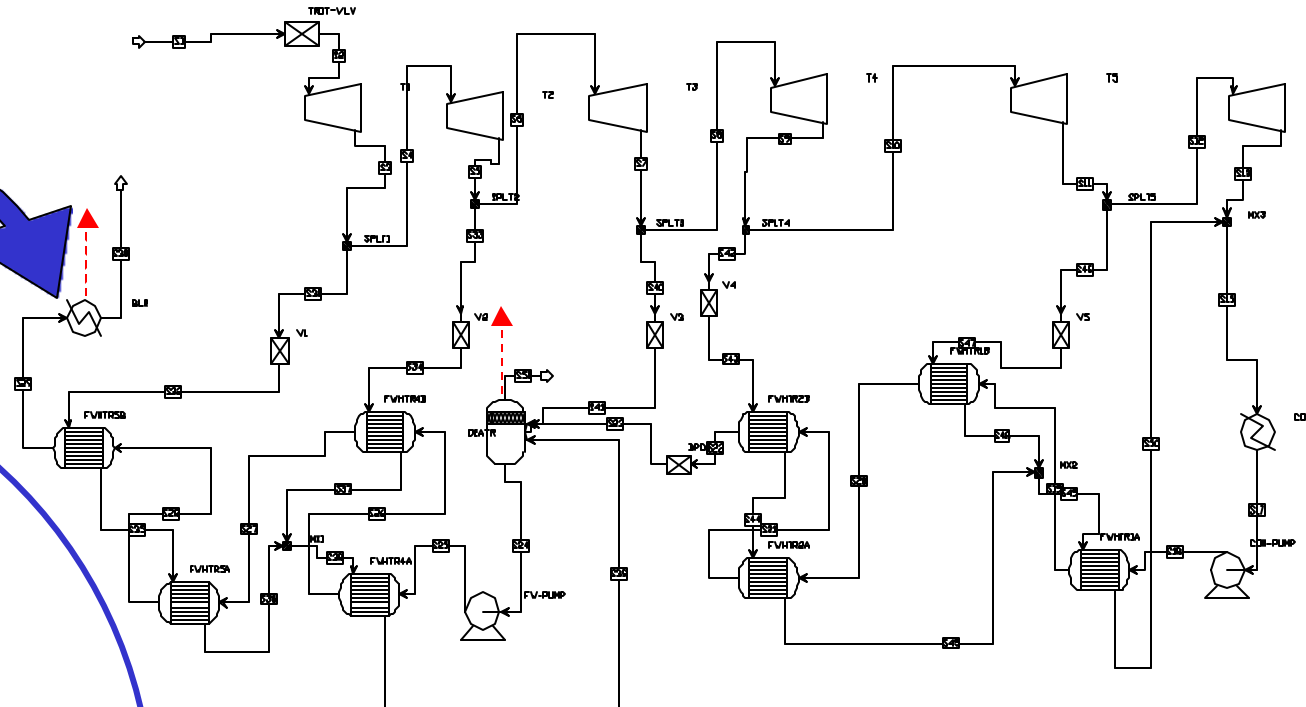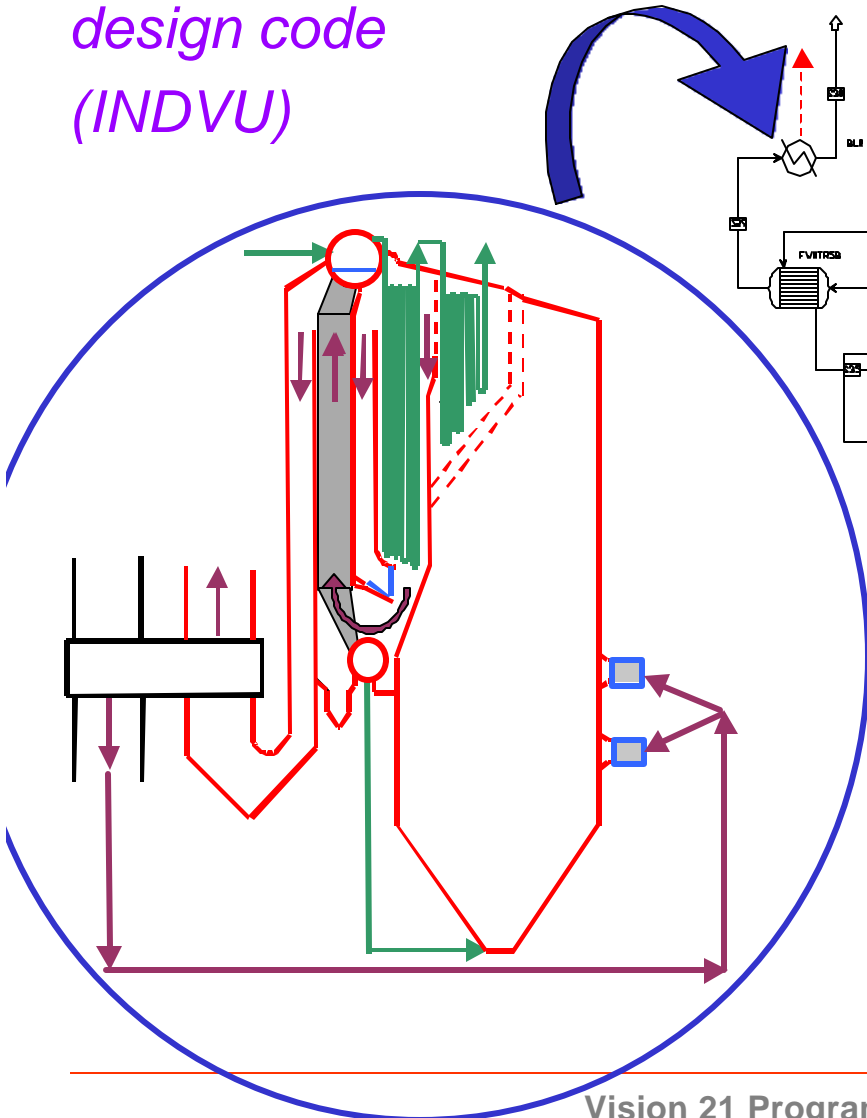
Coupling of gas-side with steam-side:

- One-way coupling (post-processing mode) prevails at high load
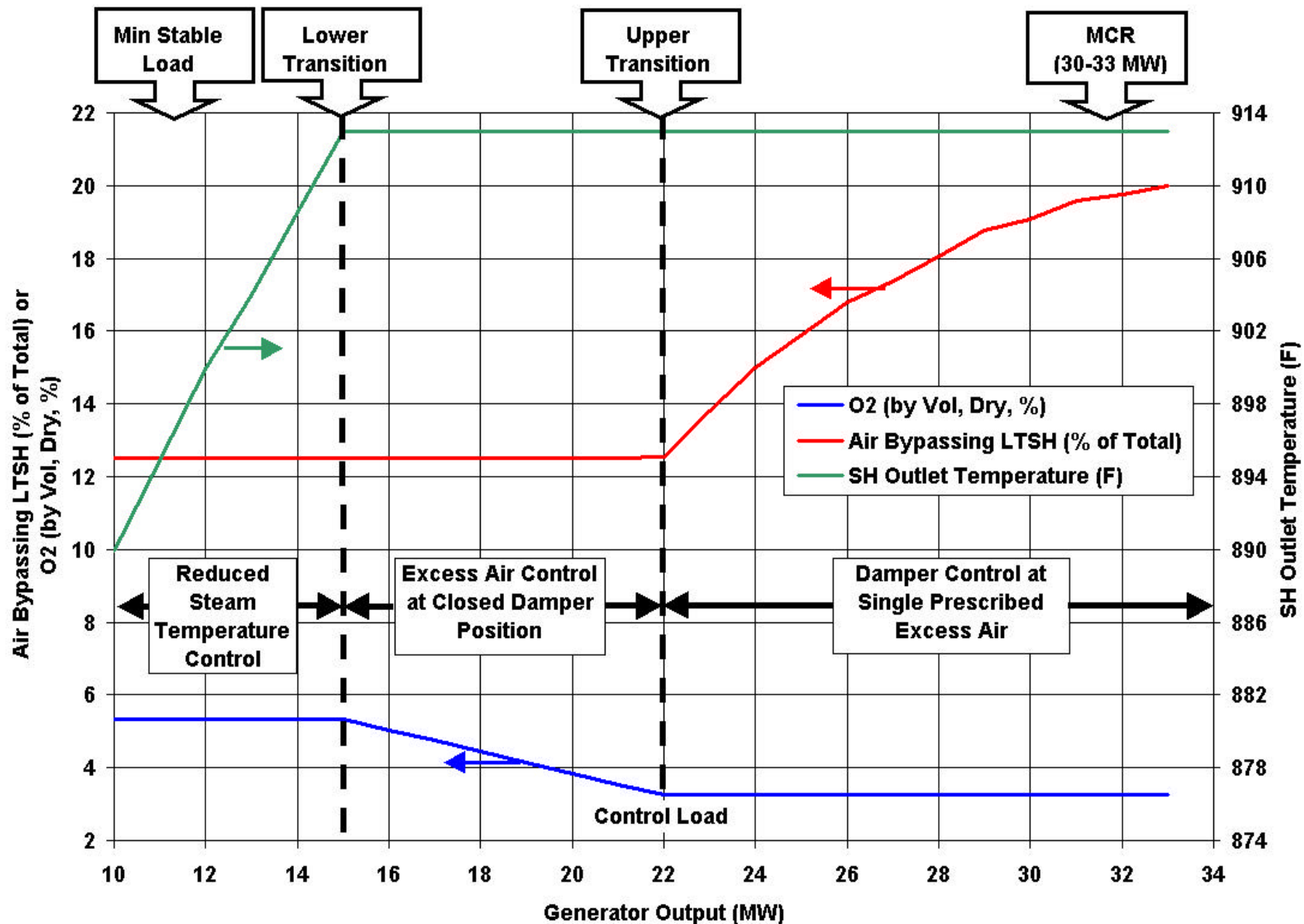
- Two-way coupling prevails at low load

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INDVU and Aspen Plus Coupling
I/O Implementation Through User Sub

(*New*) INDVU output file

INDVU Output Extractor

- **Reads output file**
- **Parses lines**
- **Extracts desired results**

Outputs to Cycle

- **SH outlet T, P**
- **AHGO / AHAO temp**
- **boiler heat duty**
- **total fuel and air flows**
- **XA**
- **FOT**

Values equated to elements in user subroutine working array (REAL vector)

INDVU Execution

- **C++ utility spawns INDVU process**
- **Reads new data file**
- **Executes code and generates new output**

(*New*) INDVU input file

Inputs from Cycle

- **FW flow rate, T, P**
- **SH outlet T, P**
- **AHGO / AHAO temp**
- **Exit O2 control**
- **Bypass control**

INDVU Input Builder

- **Reads and parses input**
- **Loads / overwrites new values**
- **Writes new input file**

(*Old*) INDVU input file (fixed format)

INDVU-Aspen User Subroutine Coupling
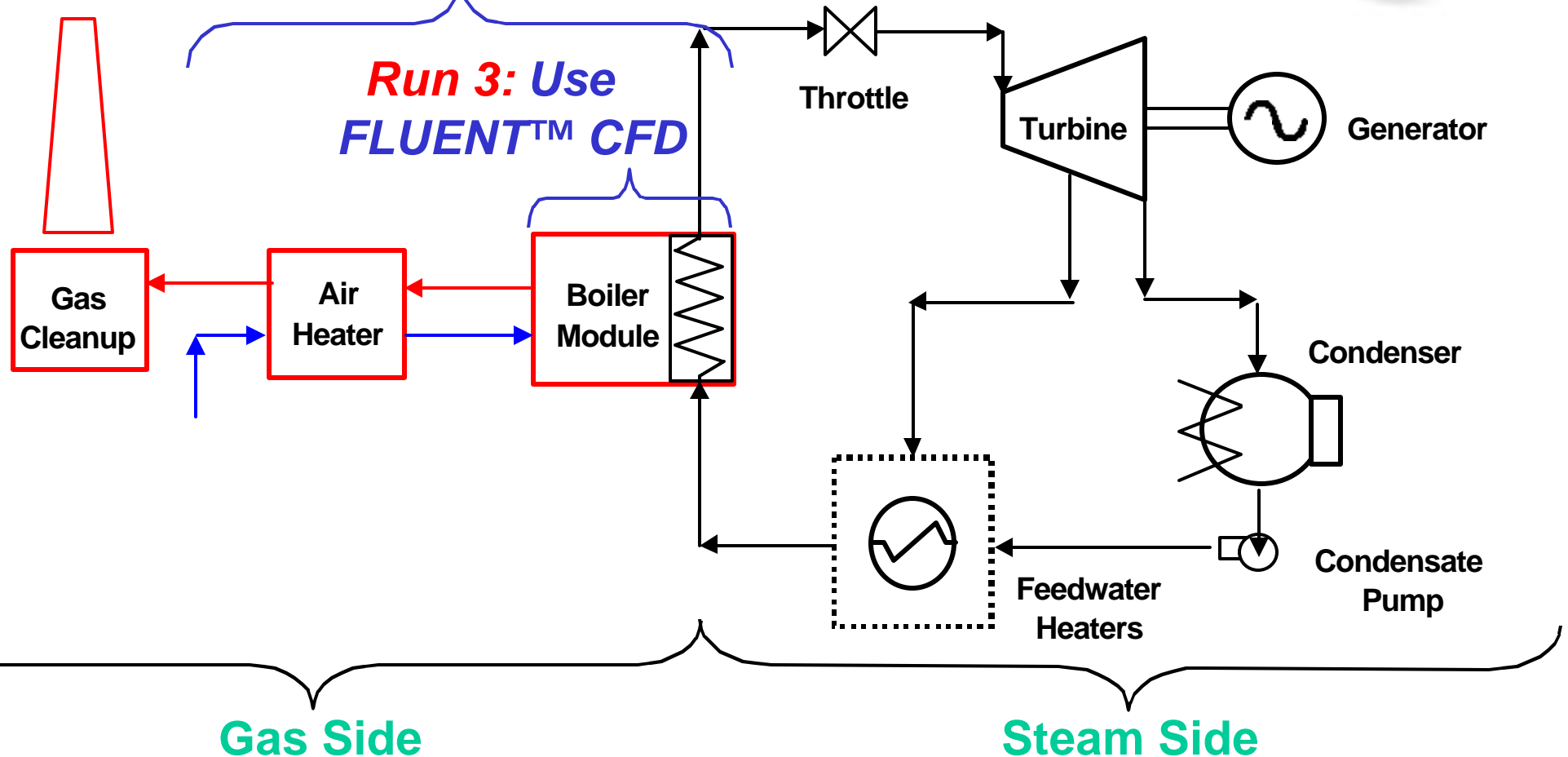## RP&L: O_2, Bypass, $T_{SH\text{-}out}$ as a f(Load)

Demo 1 Planned Runs

Run 1: Use Components from Aspen Plus Library

Run 2: Use ALSTOM Design Code (INDVU)

Run 3: Use FLUENT™ CFD

Gas Cleanup

Air Heater

Boiler Module

Throttle

Turbine

Generator

Condenser

Condensate Pump

Feedwater Heaters

Gas Side

Steam Side

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Demo Case 1: Next Steps

- <u>INDVU-Aspen Plus coupling</u>
  - Replace current user-subroutine with Cape-Open compliant wrapper -- The wrapper will serve as template for proprietary equipment models
- <u>CFD-Aspen Plus coupling</u>
  - Construct FLUENT model of RP&L boiler unit
  - Complete development of steam-side heat exchanger submodel in FLUENT
  - Couple the CO-compliant boiler model to process model via V21-Controller

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Selection of Demo Case 2

- Select advanced power generation cycle, including:
  - Natural gas combined cycle
  - Gas/Steam turbines
  - Generator
  - Heat exchange equipment (including HRSG)
  - Pumps
- Mimic Vision21 concepts
- *An advanced combined cycle case is being sought from the ALSTOM Swedish Gas Turbine Center*
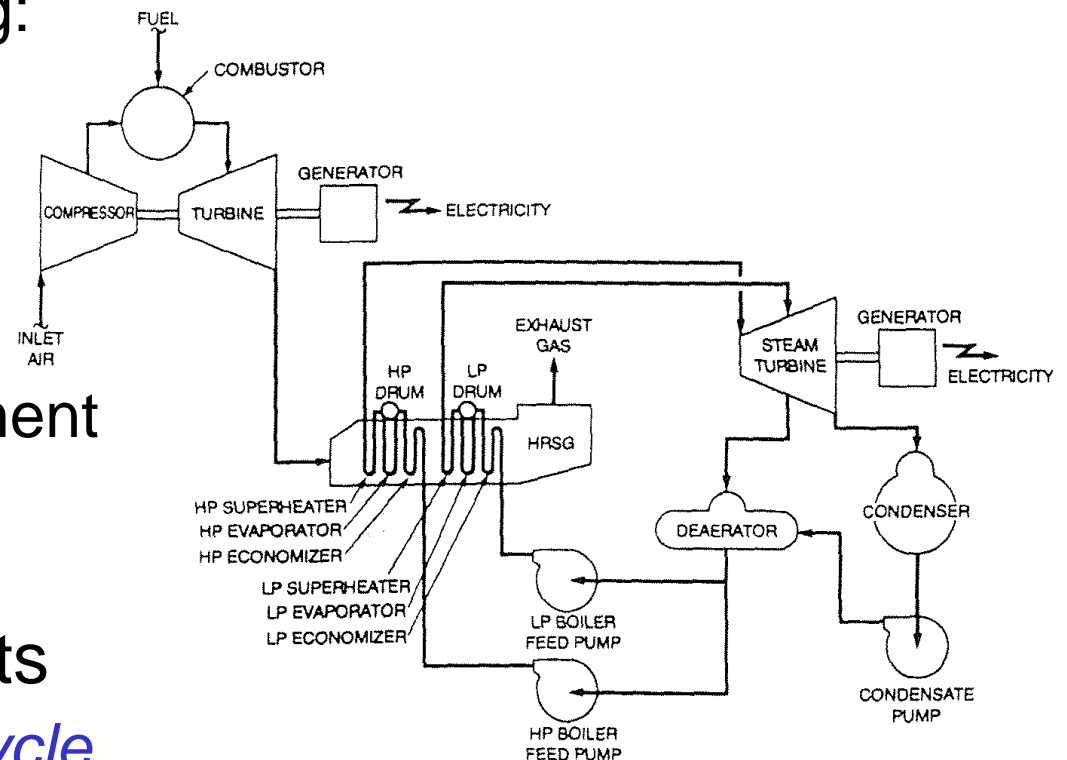
Industry Advisory Board (1)

- Purpose -- Solicit Feedback and Guide the Project Team
  - Review Progress and Conduct Demonstrations
  - Seek Feedback
  - Panel Makeup -- 5 to 6 Members
  - Meet twice per year: DOE Review Meeting / Fluent UGM
- Members:
  - Diane Revay Madden – DOE
  - John McKibben/Krista Comstock – P&G
  - Bing Sun – UOP
  - Mathew Godo – Intelligent Light
  - Ed Rubin – CMU/NAS
  - Eugene Baxter – Clean Energy Systems
  - Sanjay Mehta – Air Products
  - Jim Tilton – Dupont
  - Paul Gillis/Hua Bai – Dow Chemical
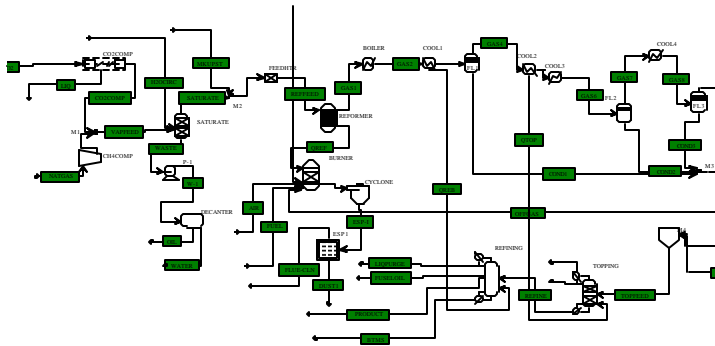 - Hossein Ghezel-Ayagh – Fuel Cell Energy Inc.

Industry Advisory Board (2)

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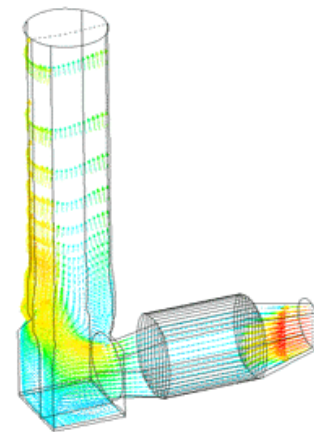Meeting, Nov. 6-7, 2001
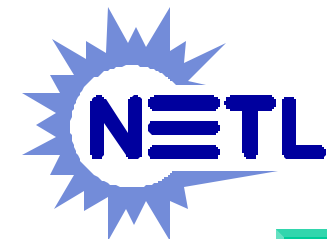
Benefits

- Capability for the complete capture of process knowledge about Vision21 technology modules
    - Leads to optimal design and improved efficiency
- Facilitate rapid technology transfer to industry
    - Use market-leading software – Fluent, Aspen Plus
    - Use standard software interfaces – CAPE OPEN
    - Industry Advisory Board

Process Simulation + CFD = Power Plant of the Future

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Thank You!